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College of Agriculture
College of Engineering

Current and Emerging Technologies for Large Scale Production of Cellulosic Ethanol

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Laboratory of Renewable Resources Engineering
Agricultural and Biological Engineering

Purdue University



Acknowledgements

US Department of Energy Office of the Biomass Program,
Contract DE-FG36-04GO14017, CPBR

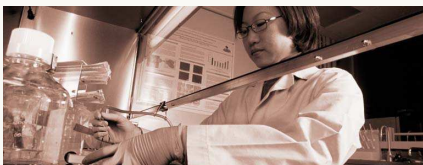
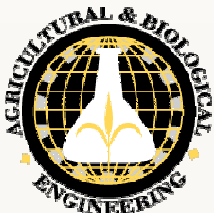
Dow Agrosciences

Genencor International

State of Indiana

Sonny Ramaswamy, Randy Woodson
Purdue University Agricultural Research Programs

Nathan Mosier, Wilfred Vermerris



Making Ethanol

Convert Biomass to sugars (pretreatment and enzymes)

Convert Sugars to ethanol using yeast or bacteria (fermentation)

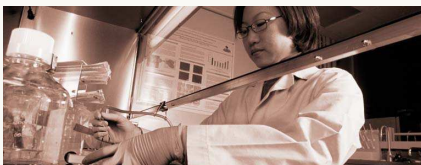
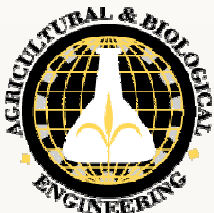
Remove water from ethanol (separations)

Blend ethanol with gasoline

E10 = 10% ethanol

E85 = 85% ethanol

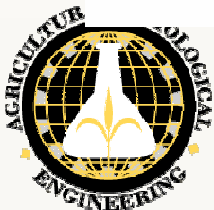
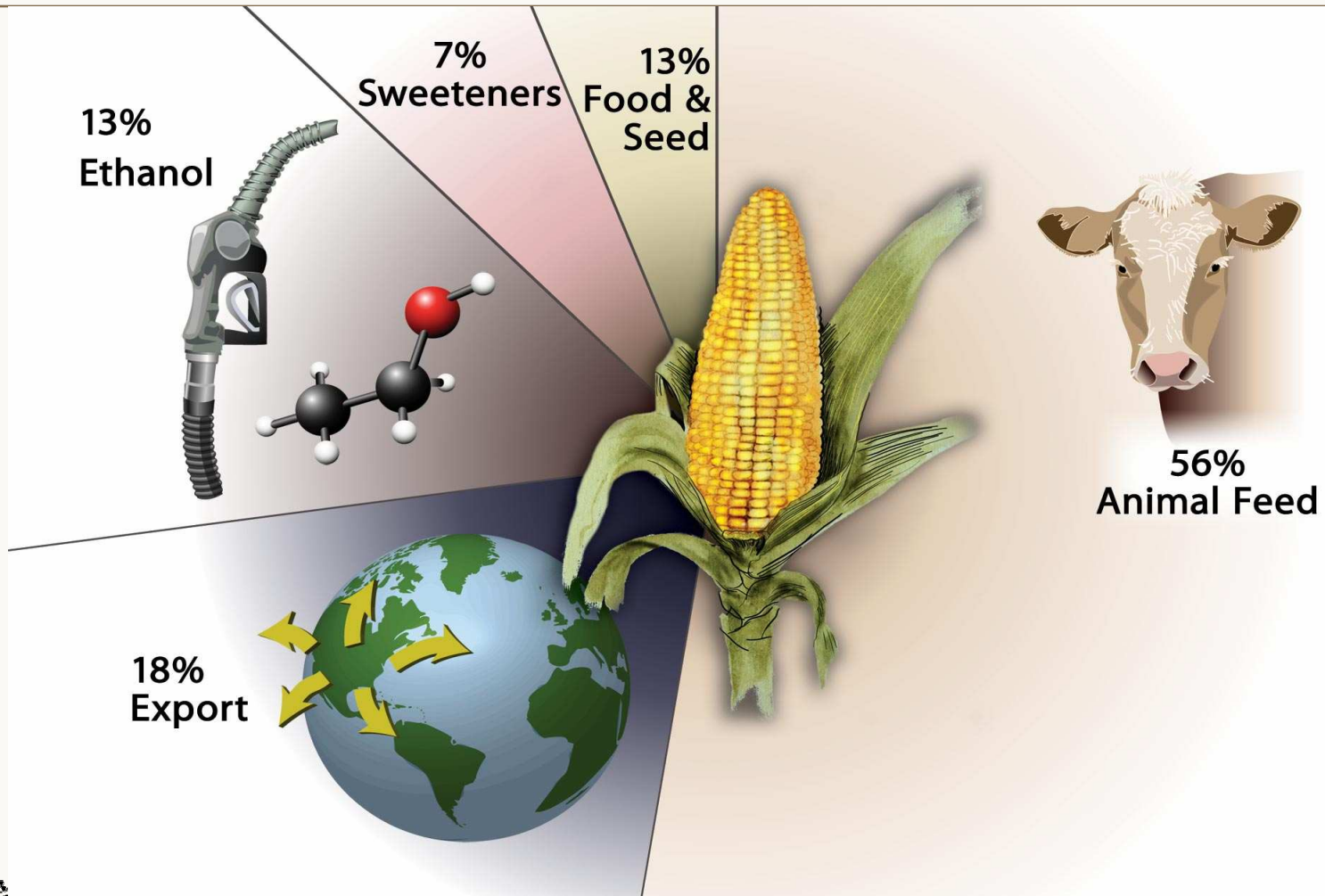
Biotown experiment



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Corn



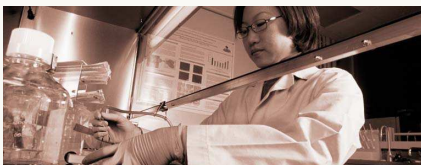
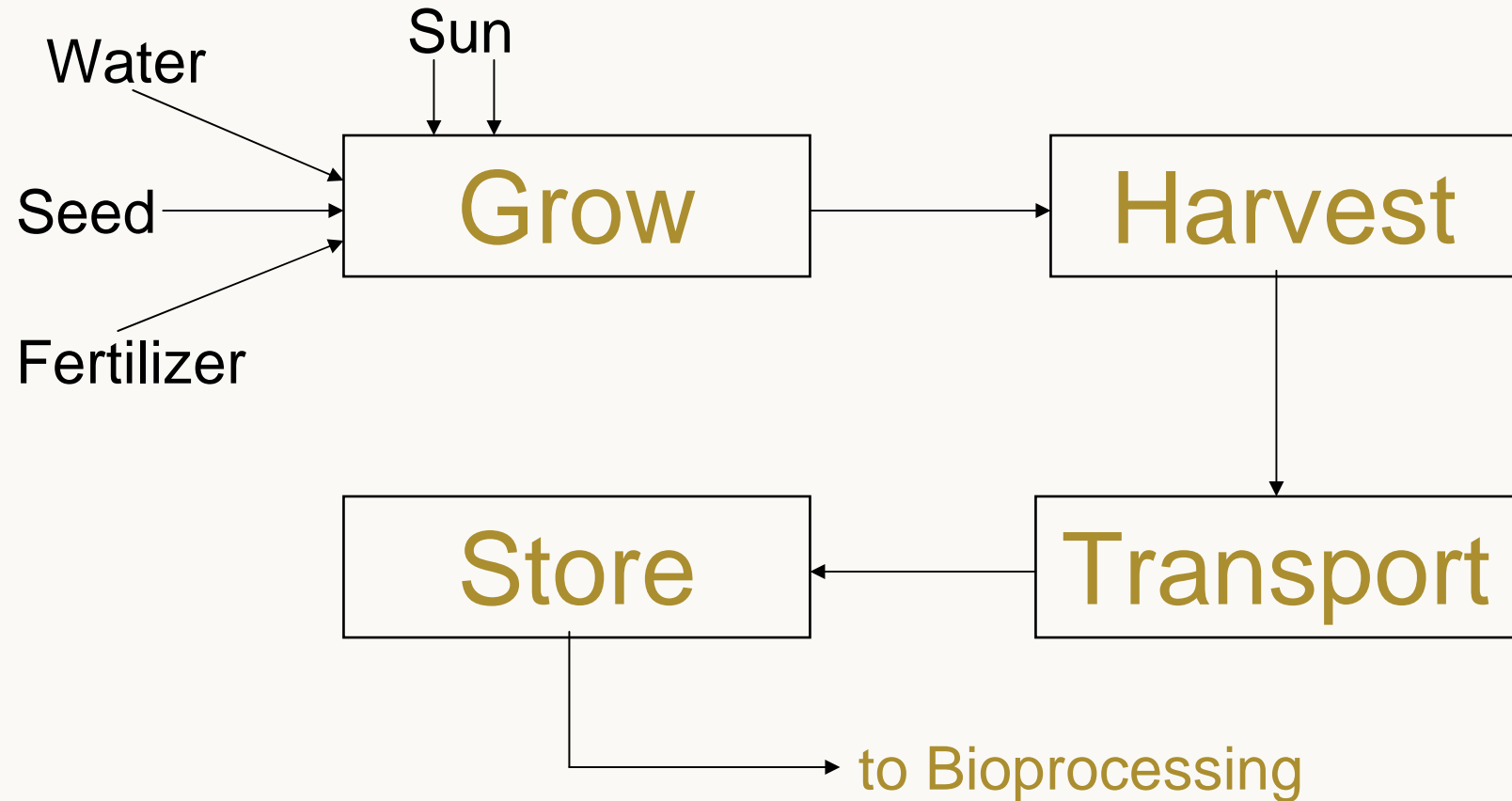
Source:

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colle Rager Fuller, National Science Foundation

Supply Chain



Build on Existing Infrastructure for Corn

Trucking the feedstock

Trips of 5 to 40 miles, one way, for corn

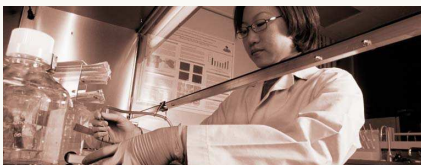
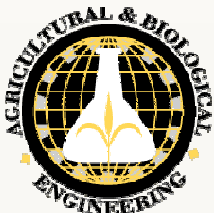
Costs about

12 cents per bushel corn

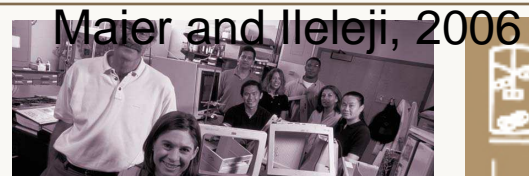
4.6 cents per gallon ethanol

\$ 5 / ton (dry basis) corn

10 cents per cu. ft. corn

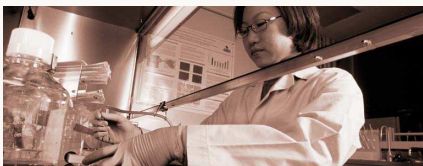
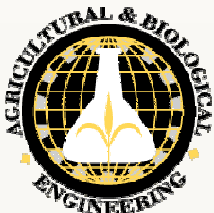
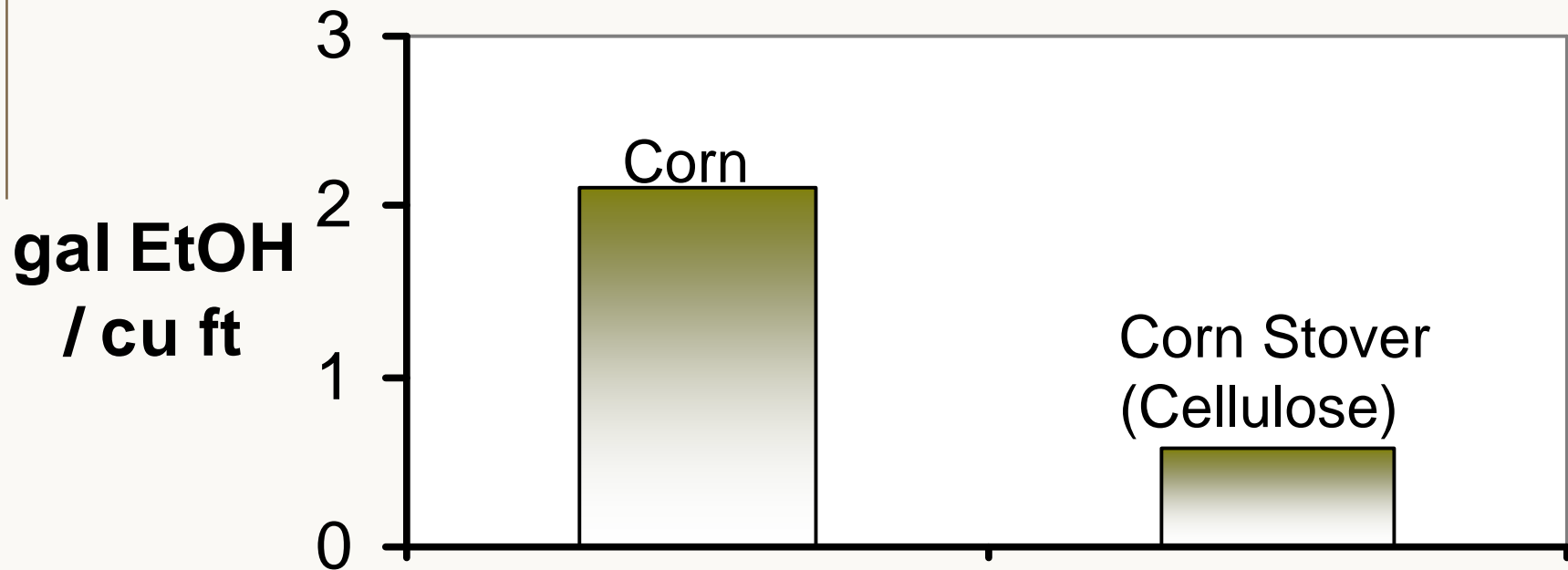


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Corn Weighs more than Corn Stover (Cellulose)

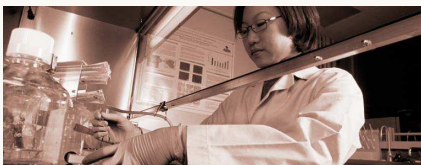
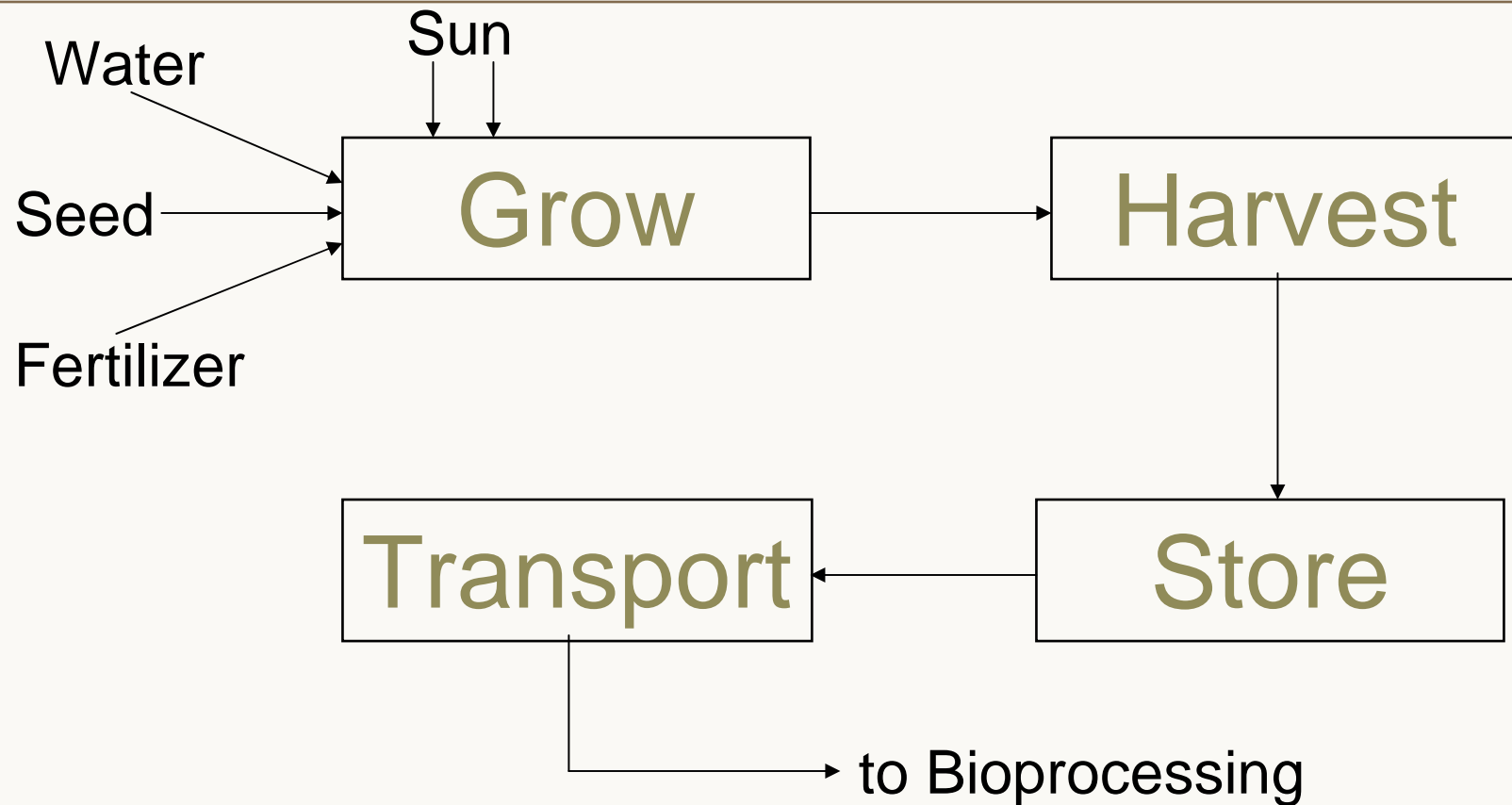
translates to larger storage volumes for cellulose feedstock for a given ethanol production



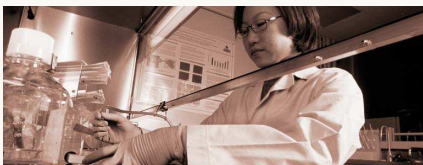
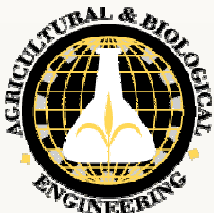
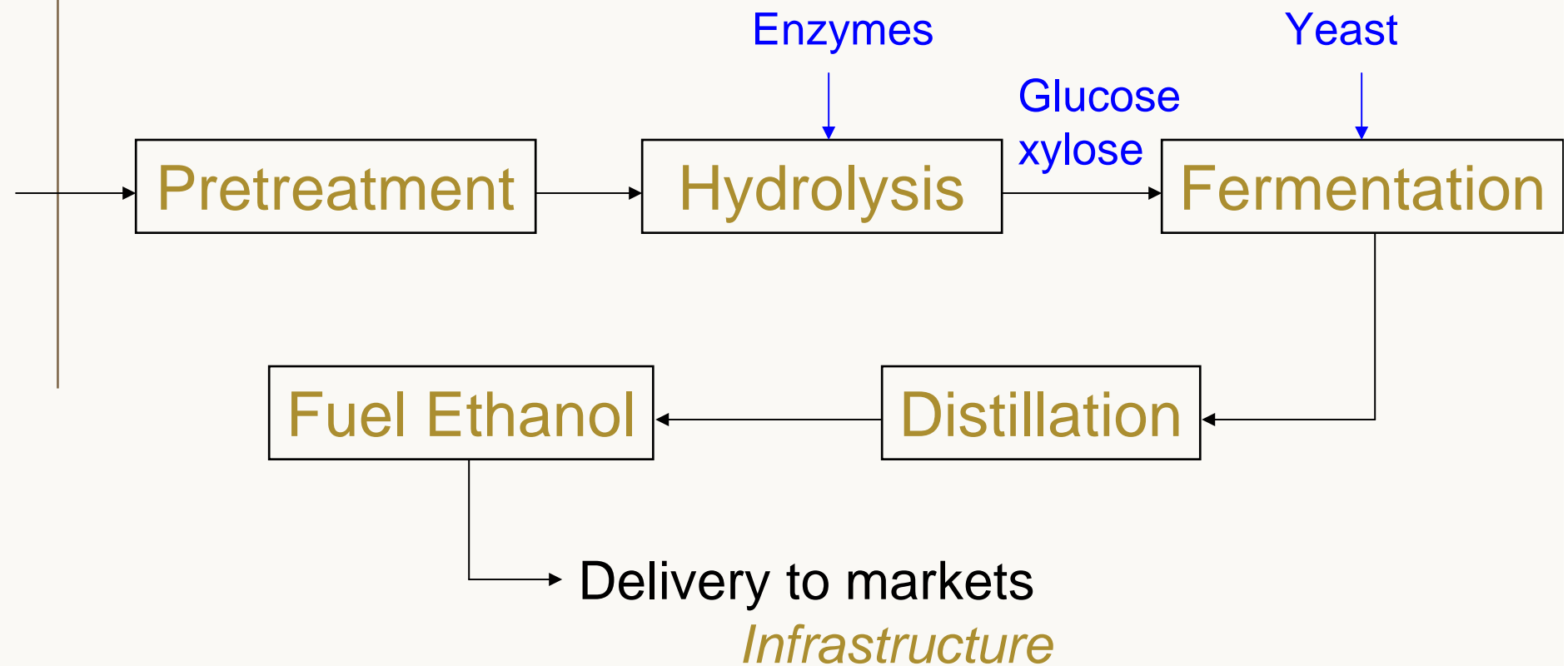
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Supply Chains: Store, then Transport



Bioprocessing

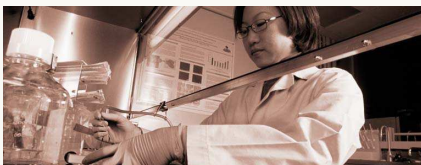


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Projections: US Ethanol Production

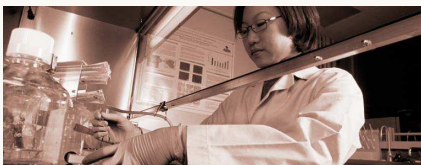
2006	4.8 (corn)
2008	7.5 (corn + cellulose)
2015	12.0 (corn + <u>more cellulose</u>)
2030	60.0 (<u>a lot of cellulose</u> + corn)



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Ethanol Plant Locations

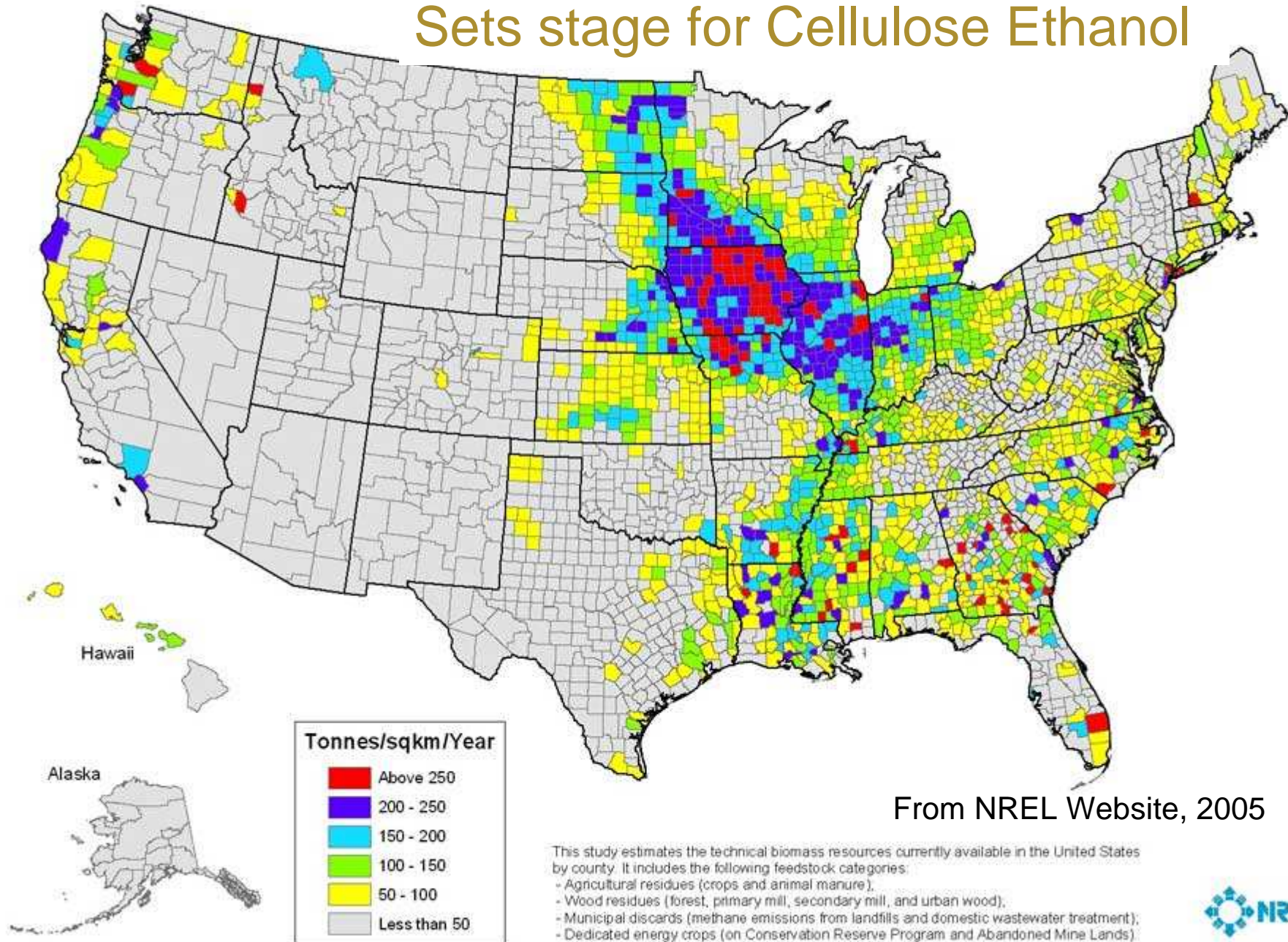


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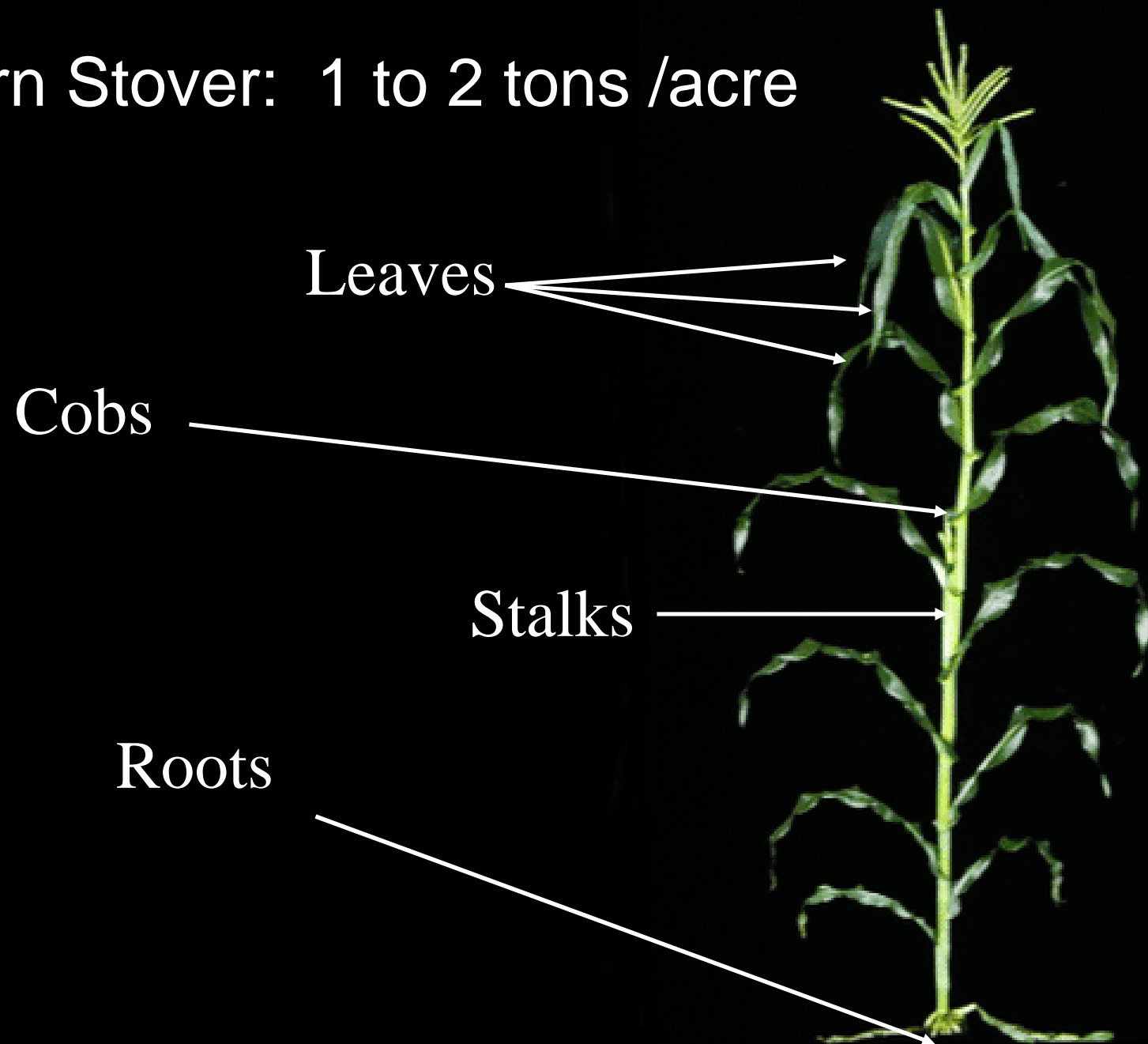


Biomass Resources in Tons / sq km /year

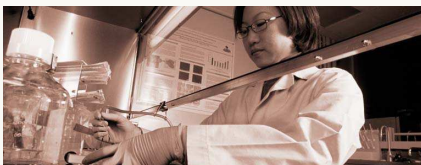
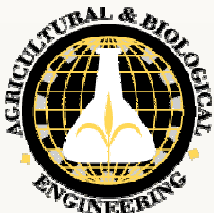
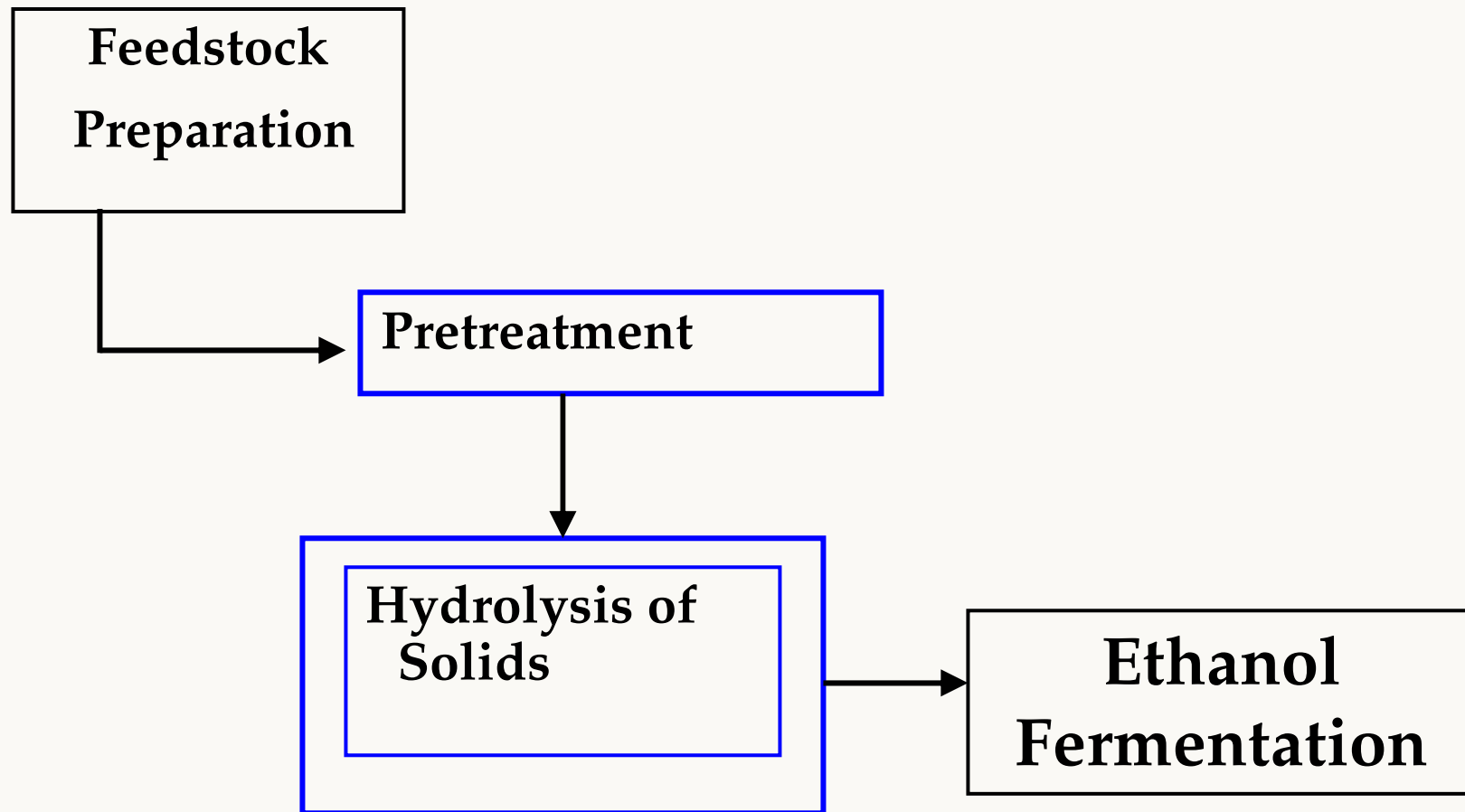
Sets stage for Cellulose Ethanol

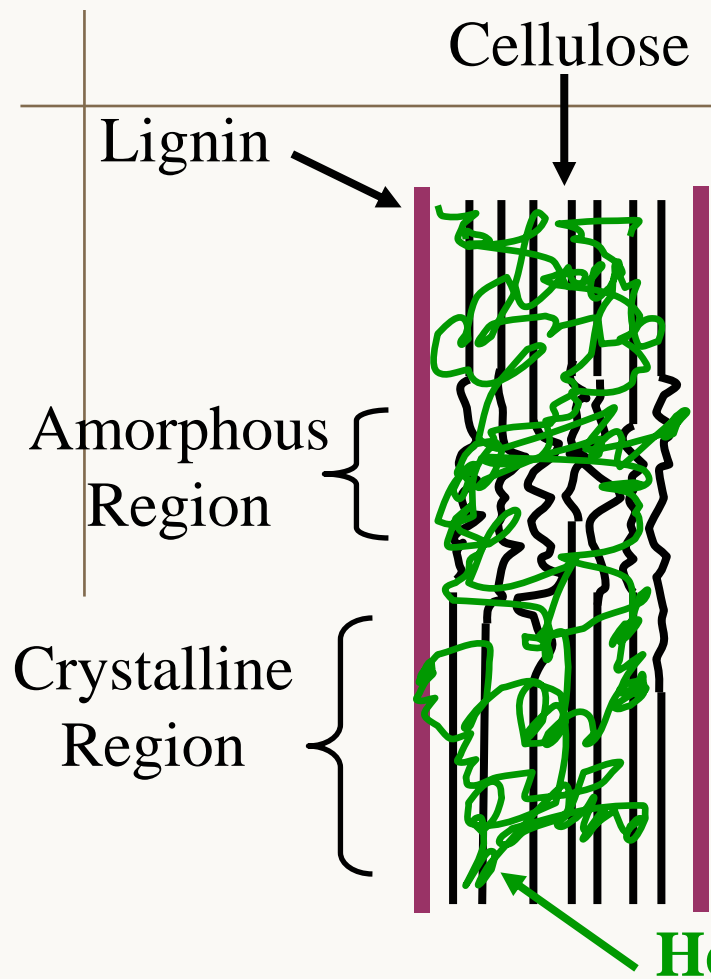


Corn Stover: 1 to 2 tons /acre



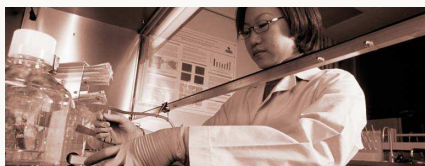
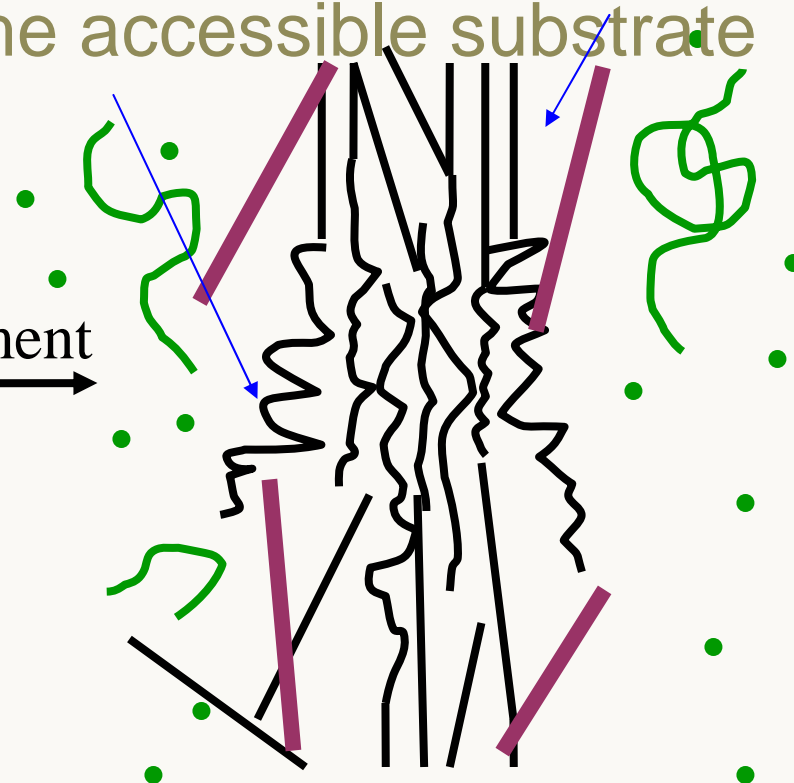
Bioethanol Production





Pretreatment gives
enzyme accessible substrate

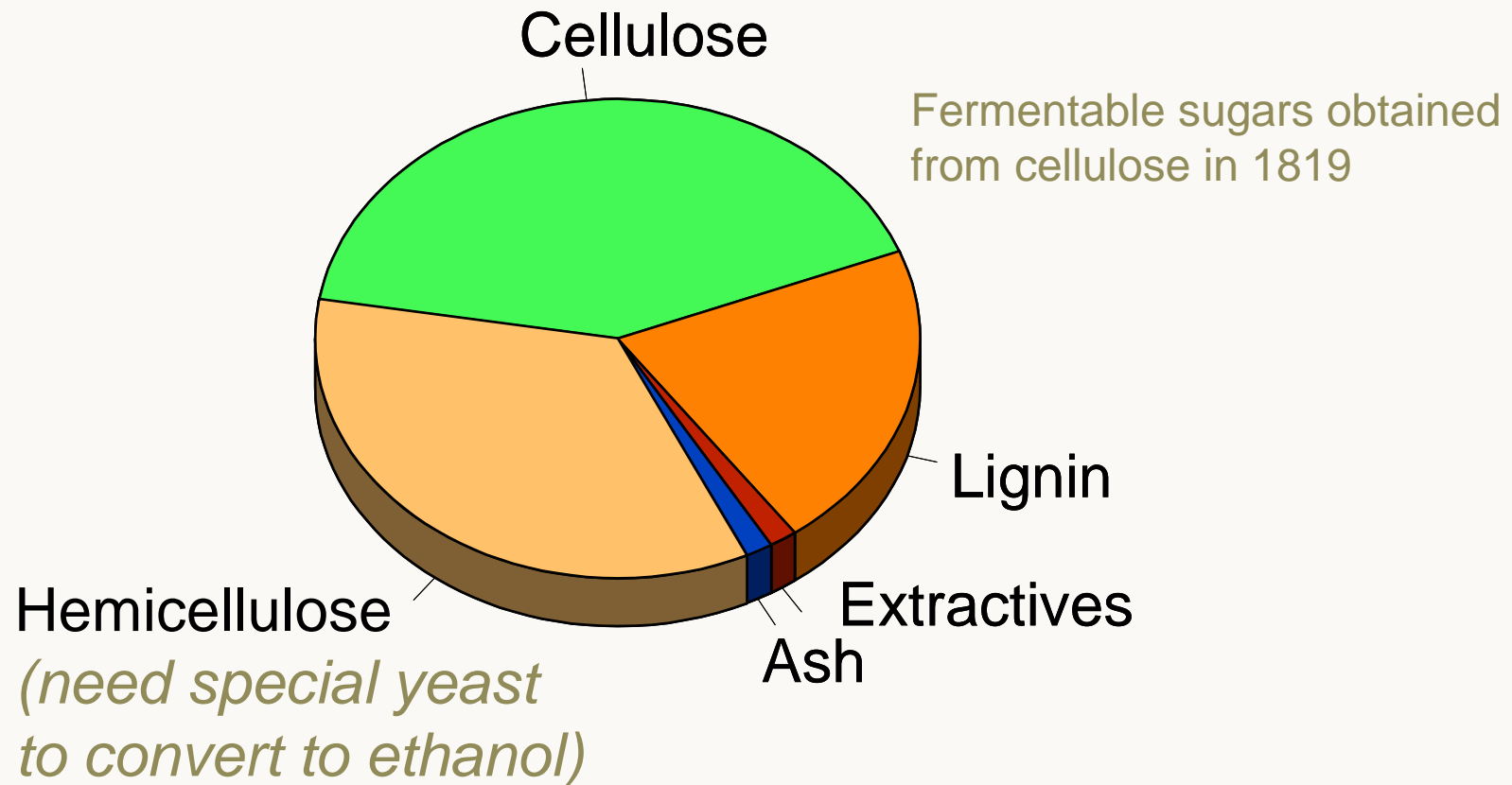
Pretreatment



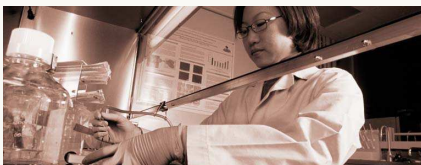
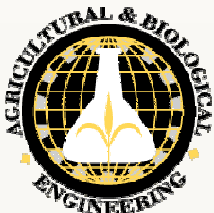
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Components of plant cell walls



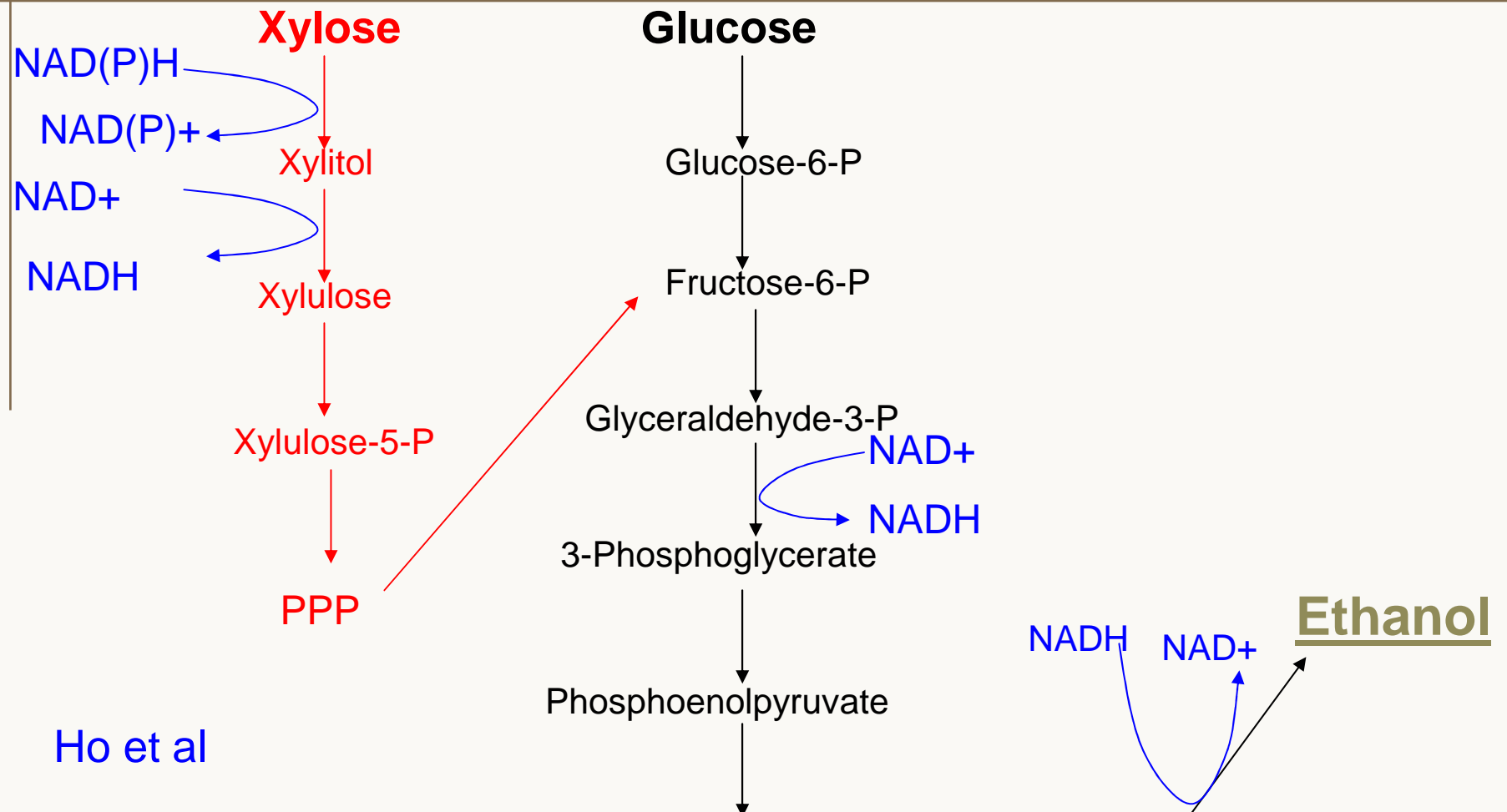
Chapple, 2006; Ladisch, 1979



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Yeast Metabolism: pentose fermentation



Ho et al



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Yields of Ethanol from Corn Stover (Cellulose Ethanol)

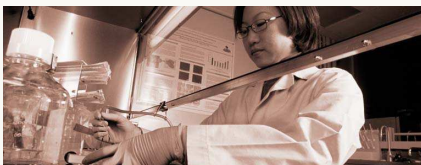
From Cellulose: 50 to 55 gal / ton

From Xylan: 30 to 35 gal / ton

Total: 80 to 85 gal / ton.

Corresponds to about 250,000 tons /yr for 20 million gal per year plant

Requires engineered yeast, pretreatment , cellulase enzymes



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Other molecules from biomass sugars

Fermentable sugars are the feedstock

Products in addition to ethanol

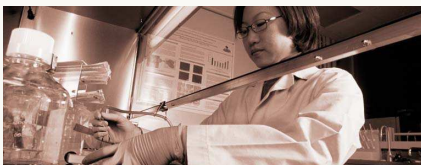
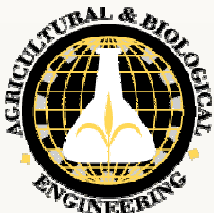
Butanol, Acetone

2,3 Butanediol

Acetic, Lactic acid

Microbial polysaccharides (for enhanced oil recovery)

Ladisch et al, 1979; 1991



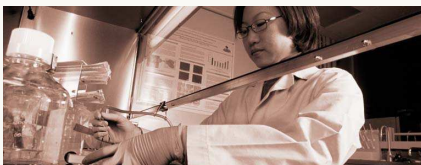
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Plant Cell Wall Genomics

Identified over 1100 genes involved in cell wall construction
Generated over 900 mutants in Arabidopsis and 200 in maize;
maize mutants represent a resource of genetic diversity
for feedstock testing
Characterized cell walls of these materials using spectroscopic,
chemical, and imaging assays
Identified novel cell-wall genes that can contribute to feedstock
diversity
Used genetics and molecular biology to analyze the functions of
cell-wall gene products

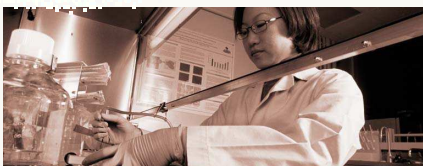
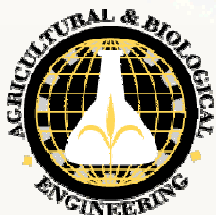
<http://cellwall.genomics.purdue.edu>



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Trees: 5 to 10 tons /acre



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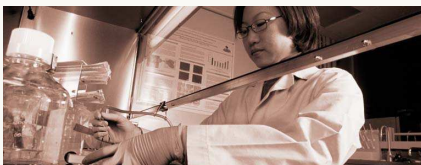
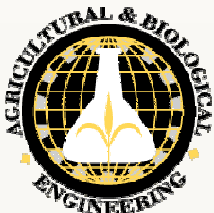
Chapple and Meilan, 2006
<http://www.gvrd.bc.ca/>



Switchgrass: 5 to 10 tons /acre, less inputs



Elbersen, Wageningen, 2004



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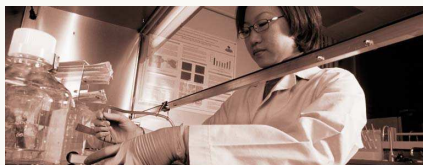
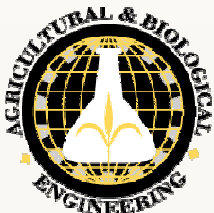


Using Hay

1 Bale = 970 lbs = 2000 miles



Assuming 50 gal x 40 mpg



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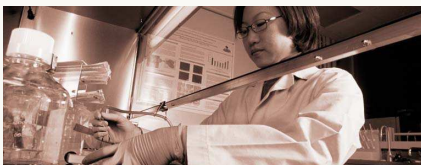
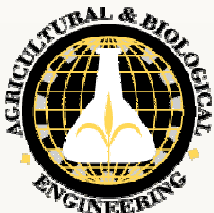
Vision

Learning and engagement to illustrate science and engineering as agents of change

Transfer discovery from laboratory to the field or plant in a contiguous high tech / biotech / agriculture corridor

Combine engineering, science and agriculture to catalyze of sustainable growth of a US bioenergy sector

Work is not complete until it proven valuable to industry.



Challenges: What will it take?

Utilize biomass materials from a wide range of sources:

Cellulosics

Fiber

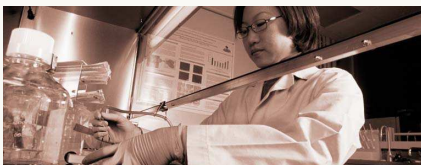
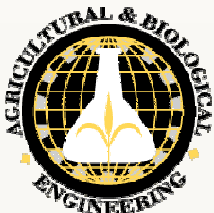
Corn

Apply biotechnology and nanotechnology to
develop bio-catalytic conversion routes

Yeasts

Fixed bed catalysts

Enzymes



Opportunities

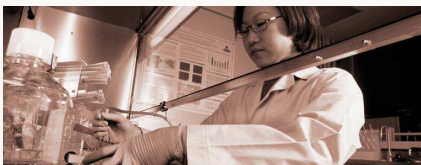
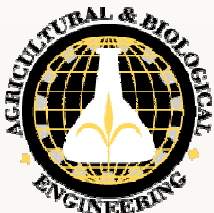
Designer crops for bio-energy production

Bioprocess Engineering built around advanced biocatalysts (yeasts, enzymes, fixed bed catalysts) that process designer crops

High energy corn that maximizes polysaccharides rather than oil or protein

Understand role of forages (switchgrass) and wood poplar grown for energy crops

Seeds for the same



Research

Plant genomics

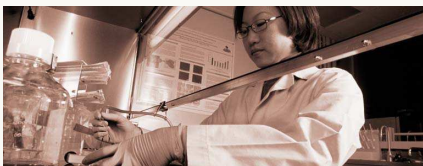
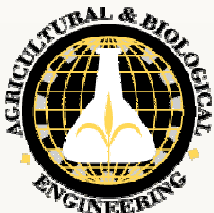
Microbial genomics

Bioprocess Engineering

Agriculture

Economics

Industrial Test Beds



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